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Development of Sludge Bed in Upflow Anaerobic Reactors Treating Combined Industrial Effluent

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Abstract: In this study the effect of development of sludge bed on the efficiency of Upflow Anaerobic Sludge Blanket (UASB) and Upflow Anaerobic Sludge Filter (UASF) reactors, operating at HRTs 3 to 12 h and sludge age of 30, 60, 90, 120 and 150 days was investigated. The effect of temperature on the granulation of UASB sludge was more pronounced as compared to the attached microbial growth in the UASF. For UASB reactor, average concentrations of VSS and TS increased steadily up to sludge age of 120 days, beyond which VSS and TS contents decreased significantly due to sludge liquidation. For UASF reactor, average concentration of VSS increased steadily even beyond day 120, whereas average TS content increased from day 30 to day 60 and it decreased after 60 to day 90, mainly attributed to the expansion in the sludge height due to fluidization of the bed. XRD analysis of the UASF sludge showed the presence of expanding clays revealing its additional absorption capability. Fuoraphyllite and Albite precipitation in reaction with Calcium and Phosphate related to excellular polymers of the microbial shell structure, showed the extended growth of microorganisms during sludge granulation in the UASB reactor.

Key words: Anaerobic treatment, UASB, UASF, sludge granulation, XRD analysis

INTRODUCTION

The interest in anaerobic wastewater treatment for environmental protection and recovery of renewable resources is increasing worldwide (van Haandle and Lettinga, 1994; Annachhatre and Amatya, 2000). Anaerobic treatment particularly offers very attractive prospects for developing countries due to its high efficiency, cost effective nature and simplicity in construction and operation (Lettinga and Pol, 1991). It can contribute significantly to the improvement of environmental conditions in the developing countries.

Among the high rate anaerobic reactors, the UASB reactor (Fang *et al*., 1995) has been widely used. The success of the UASB reactor lies in its capability to retain a high concentration of immobilized active biomass because of the granulation of sludge particles (Hulshoff Pol, 1989). The granulation is a process in which a non-discrete flocculent biomass begins to form discrete well-defined pellets, or granules. These vary in dimension and appearance depending on the wastewater and reactor conditions, but generally attain spherical geometry with a diameter of 1 to 3 mm.

The sludge granulation in anaerobic wastewater treatment is dependent on many factors such as hydraulic retention time (Bal and Dhagat, 2001), organic loading rate (Punal *et al*., 2001), oxygen tolerance (Gerritse and Gottschalk, 1992), suspended solids (Lettinga and Pol, 1991) and type of seed sludge (Yang and Anderson, 1993). Several other factors, such as sludge flotation and inhibition due to the effect of fats and long-chain fatty acids, or the adsorption of finely dispersed colloidal matter on the surface of the sludge, may cause the granulation process to be difficult or the granular sludge to deteriorate (Sayed *et al*., 1987). When the UASB system is seeded only with non-granular anaerobic sludge, it can take several months before a highly effective granular bed can be cultivated, therefore the extended start up periods can limit the potential use of these systems.

In this study an attempt was made to investigate the process of development of sludge bed in UASB and UASF reactors at various sludge ages. XRD analysis of the sludge was also performed to identify the microbial growth and sludge granulation in the reactors.

MATERIALS AND METHODS

Wastewater characteristics and analytical approach: Wastewater used in this study was obtained from the combined industrial effluent drain carrying the effluents of more than one hundred textile units along with five

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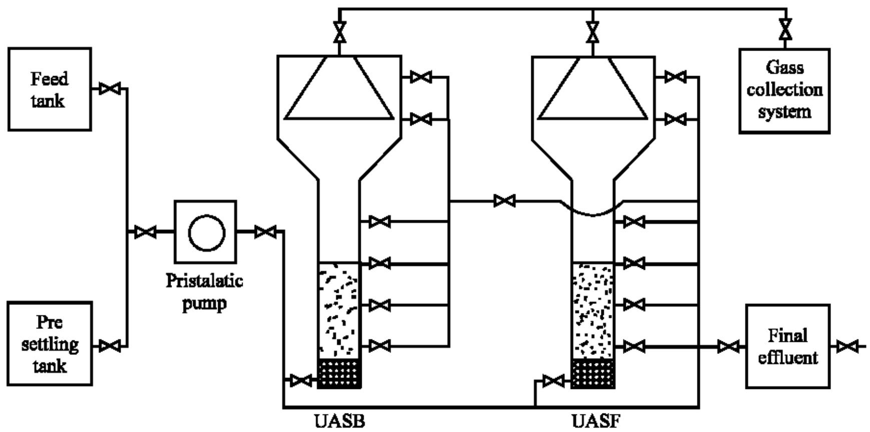

Fig. 1: Schematic of Anaerobic treatment assembly

dairy, two sugar and three flour mills. Integrated samples were prepared by mixing the water samples taken across the drain at varying depth. Wastewater samples were analyzed in terms of Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD_5), Total Kjeldhal Nitrogen, Conductivity, Turbidity, Dissolved Oxygen (DO), Total Dissolved Solids (TDS), Total Suspended Solids (TSS), Total Solids (TS), Total Fixed Solids (TFS), Volatile Suspended Solids (VSS), Total Hardness (TH), Chlorides, pH, Temperature and heavy metal contents of influent and effluent. All the tests were carried out in accordance with standard methods for the examination of water and wastewater (APHA, 1998).

Description of experimental system: A bench scale anaerobic experimental setup was used for the wastewater treatment (Fig. 1). The experimental assembly is divided into four parts: (i) fixed bed UASB reactor, (ii) feed tank, (iii) gas collection arrangement and (iv) effluent (treated) collection tank. The UASB/UASF reactor were made of Perspex tubular column (tubing) with an inside diameter (ID) of 7 cm, a length of 120 cm and a volume of 5.3 L.

In order to enhance the capturing of suspending particles and reduce their washout, an enlarged portion termed as Gas-liquid-solid Separator (GLSS) was added at the top of the column, giving the reactor a total height of 160 cm and a total volume of 15.5 L. Lower half of the GLSS was inclined entity with a slope angle (Ø) of 60°, whereas upper half was a tubular section with an Outside Diameter (OD) of 23 cm and an Inside Diameter (ID) of 22 cm. The reactor was equipped with six sampling probes placed at various heights from bottom to top the reactor is mounted on a rectangular Perspex plate of dimension 2.5 ft^2 (Fig. 2). A canopy with upside down was fixed with the top lid of GLSS (OD) (1) to facilitate capturing of

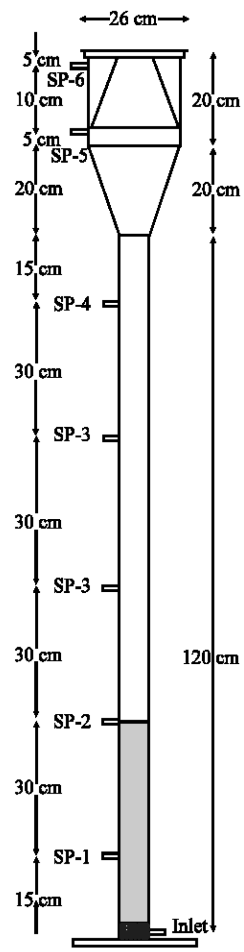

Fig. 2: Front view of the upflow reactor

biogas generated during the wastewater treatment (2) to enhance the mixing and to allow coagulation of suspended/colloidal particles (unsettled particles of the lower slant portion of GLSS).

Development of the sludge bed: The reactors (UASB/UASF) were seeded with sludge from two different sources. The UASF reactor was seeded with anaerobic sludge of the Hudiara drain bed (sediments), which was mainly comprised of sand particles with attached microbial growth and organic matrix. The content of Total Solids (TS) and Volatile Suspended Solids (VSS) of the seed sludge were 890 and 10.5 g L^{-1}, respectively. A substantially higher level of TS as compared to VSS was due to the inert material and sand particles with higher specific gravity (Malina and Pohland, 1992).

Anaerobic sludge mass for UASB reactor was developed by stabilizing the aerobic waste sludge (activated sludge) of a dairy wastewater treatment plant. During stabilization, the reactor was fed with synthetically prepared water with C: N: P ratio of 300:5:1. Color of activated sludge was started changing from white to grey in the 4th week and then it became dark grey in the fourth week. Decomposition of the activated sludge resulted in the release of cellular material into the liquid, which was consumed by the anaerobic bacteria as food.

The volume of the sludge was reduced by 33% due to the settlement of the sludge bed during the first thirty days. At this stage, TS and VSS content of seed sludge were 33.5 and 18.6 g L^{-1}, respectively. Wastewater from the point where drain joins Ravi was then introduced to the reactor to acclimatize the sludge. After sixty days, sludge granulation was appeared. Sludge granules were very well developed after seventy-eight days.

XRD analysis: Sludge samples were dried at 60°C overnight and were ground in a ceramic pestle and mater. The ground samples were sieved in # 200 sieve. The un-oriented cavity mounts were prepared for bulk mineralogy. Samples were run from 2°2θ to 60°2θ on a Siemens D-5000 diffractometer, α radiations along with Cu and Ni filters were used at 40 Kv and 30 mA.

RESULTS AND DISCUSSION

The effect of aging on sludge composition was monitored at sludge ages varying between 30-150 days. The average contents of TS and VSS were found to be about 39 and 21 g L^{-1}, respectively in UASB reactor at sludge age of 30 days (Table 1). While TS and VSS contents were 918 and 11.3 g L^{-1}, respectively in case of UASF reactor (Table 2). At sludge age of 60 days an over all increase in TS and VSS concentrations from 39 and 21 g L^{-1} to 53.7 and 31.7 g L^{-1} for UASB and from 918 and 11.3 g L^{-1} to 925 and 18.9 g L^{-1} for UASF reactors was observed. The increase in TS concentration was mainly due to settling of the sludge while VSS concentration clearly demonstrated the production of biomass. Actually, the maximum specific growth rate of bacteria depends upon the food over microorganism ratio (F/M) and is directly related to maximum specific substrate utilization rate (Baily and Ollis, 1986). Nevertheless, due to favorable temperature and availability of nutrients there was an appreciable increase in the TS and VSS concentrations (up to 66.7 and 48.6 g L^{-1}, respectively) in UASB reactor at sludge age of 120 days. TS concentration in UASF was appeared to be slightly dropped (from 925 to 919 g L^{-1}), whereas VSS content was increased from 18.9 to 35.4 g L^{-1} attributed to the microbial growth attached with sand particles. However, a slight drop in TS content was due to bed expansion in a result of entrapment of the gas bubbles within the sludge bed. The expansion of bed in such reactors may go up to 20% of the height of the bed (Metcalf and Eddy, 2003). Beyond day 90, TS and VSS contents were increased to 66.7 and 48.65 g L^{-1} for UASB, while for UASF these were 919 and 35.4 g L^{-1}, respectively. The increase in average VSS concentration was quite obvious as compared to TS which clearly demonstrated that increase in VSS content was due to the growth of the active biomass. In fact, the VSS in the reactor is predominantly (more than 90%) because of active biomass; whereas a small fraction (10%) is referred to non-biodegradable VSS and dead cell debris (Metcalf and Eddy, 2003). At sludge age of 150 days, there was a significant drop in TS and VSS concentrations for UASB reactor. This drop could be due to the liquidation of the granules due to temperature drop. The granular sludge can also be deteriorated due to some other factors like the effect of long chain fatty acids and the adsorption of finely disposed colloidal matter on the surface of sludge (Sayed *et al.*, 1987). Moreover, negative effect of these factors could also be augmented due to the reduced metanogenic activity at lower temperatures (Ligero and Soto, 2002).

VSS/TS ratio represents biomass growth and its quality. Figure 3 (a and b) represents the VSS/TS ratio in UASB and UASF reactors, respectively. For UASB reactor the VSS/TS ratio was increased form 0.5 to more

Table 1: Sludge composition at different sludge ages (UASB reactor)

Parameters ($g\ L^{-1}$)	Sludge ages (days)				
	30	60	90	120	150
VSS	20.900	31.700	40.400	48.600	29.500
TFS	18.200	22.100	16.100	18.000	12.500
TS	39.200	53.700	56.500	66.700	42.000
VSS/TS	0.534	0.589	0.716	0.730	0.702

Table 2: Sludge composition at different sludge ages (UASF reactor)

Parameters ($g\ L^{-1}$)	Sludge ages (days)				
	30	60	90	120	150
VSS	11.3000	19.000	21.000	35.4000	38.4000
TFS	906.8000	906.200	891.900	883.7000	870.5000
TS	918.1000	925.100	912.900	919.1000	908.9000
VSS/TS	0.0122	0.020	0.022	0.0385	0.0439

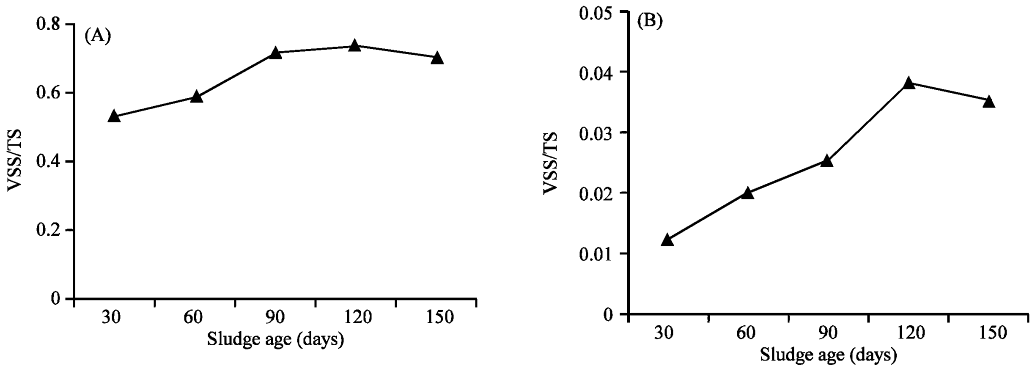

Fig. 3: VSS/TS ratios in (A) UASB and (B) UASF reactors

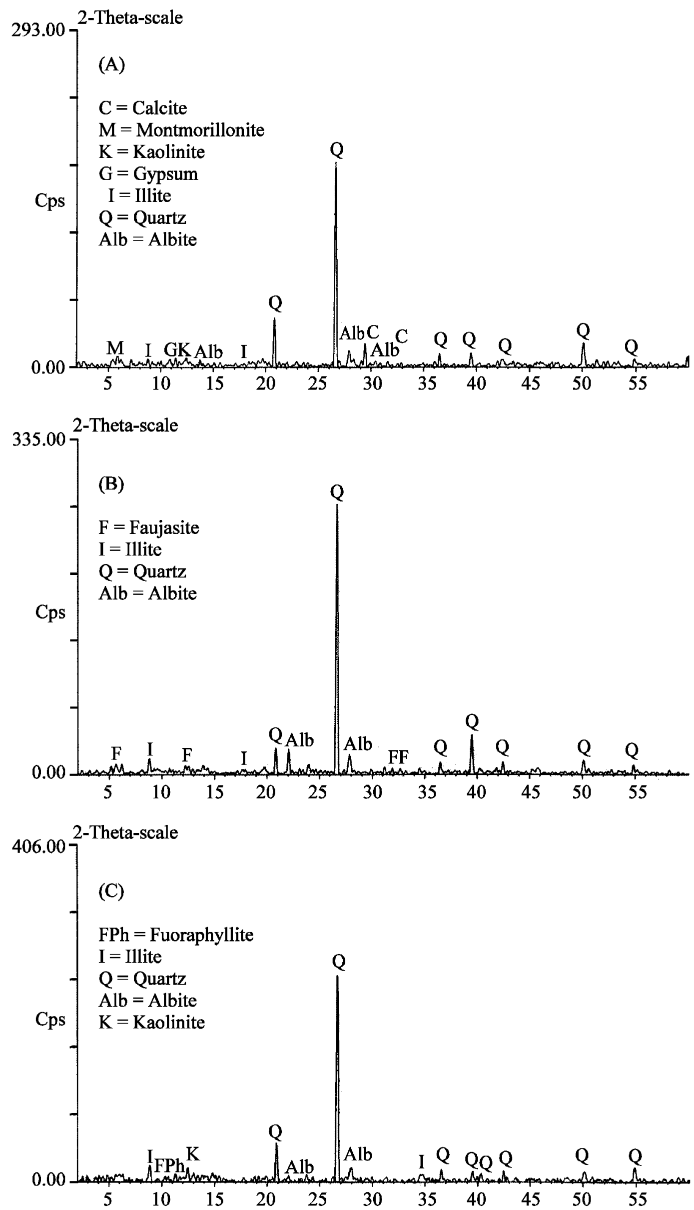

Fig. 4: X-Ray analysis of (A) UASF sludge at day 150 (B) UASB sludge at day 60 (C) UASB sludge at day 150

than 0.7 with an increase in sludge age from 30 to 90 and above days. This steady increase in VSS/TS ratio also reflects a steady increase in the granules size (Annachhatre and Amatya, 2000). Beyond sludge age of 90 days, the increase in VSS/TS ratio is marginal, even slightly decreasing trend is evident at day 150. In case of UASF reactor, the VSS/TS ratio also appears to be gradually increased (from 0.012 to 0.043) by increasing sludge age. However, VSS/TS ratio in case of UASB reactor is not striking, which can be attributed to the characteristics of the sludge.

X-Ray diffraction analysis of UASF sludge shows that it is mainly composed of clays like Illite, montmorillonite and kaolinite along with the other non clay minerals such as quartz, albite, calcite and gypsum (Fig. 4a). The presence of different clay minerals and quartz indicates that they are detrital component of the sample and the presence of well crystallize albite, calcite and minor gypsum indicate that these minerals have been precipitated by the reaction of different free cations present in the sludge e.g., calcium and PO_4 generated by the microbiological growth in the sludge has resulted in precipitation of gypsum, rest of the calcium in the presence of CO_2 generated during anaerobic digestion has resulted as calcite. Similarly release of Na, Al and Silica from clay minerals resulted in the formation of well crystallized Albite. The clay mineral Illite and expanding clay montmorillonite have the absorption capability of the heavy metals.

UASB sludge samples analysis taken at early stage of day 60 and on the final day 150 show that its dominant components are Quartz and Illite (Fig. 4b and c). In the sludge sample of 60 days Faujasite ($Na_2Al_2Si_4O_{12}.8H_2O$) and albite appeared to be formed authogenically by leaching out of cations like Si and Al from Illite. However, in the sample of day 150, Fuoraphyllite ($KCa_2(Si_4O_{20})$ FO_{20}. $8H_2O$) along with albite seems to be precipitated anthrogenically in reaction with available calcium related to excellular polymers of the microbial shell structure, which shows the extended growth of microorganisms during sludge granulation (Gonzalez *et al*., 2001; Torkian *et al*., 2003).

CONCLUSIONS

The following conclusions can be drawn from this study: Significant increase in VSS was observed with an increase in sludge age from 30 to 120 days, which shows an increase in biomass and granulation of the active sludge in UASB reactor. Beyond day 120, decrease in temperature resulted in liquidation of the sludge correspondingly decrease in VSS concentration. In UASF reactor, VSS concentration continuously increased up to day 150. The growth of active biomass continued in both the reactors with increasing sludge age while sludge granulation in UASB appeared to be dependent on temperature.

XRD analysis of the UASF sludge shows the presence of expanding clays revealing its additional absorption capability. Fuoraphyllite along with albite precipitation in reaction with available calcium and Phosphate related to excellular polymers of the microbial shell structure shows the extended growth of microorganisms during sludge granulation in the UASB reactor.

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REFERENCES

Annachhatre, A.P. and P.L. Amatya, 2000. UASB treatment of tapioca starch wastewater. J. Environ. Eng., 126: 1149-1152.

APHA, AWWA and WPCF., 1998. Standard Methods for the Examination of Water and Wastewater. American Public Health Association, Washington, DC.

Baily, J.E. and D.F. Ollis, 1986. Biochemical Engineering Fundamentals. 2nd Edn., McGaw-Hill, New York.

Bal, A.S. and N.N. Dhagat, 2001. Upflow anaerobic sludge blanket reactor-a review. Ind. J. Environ. Health, 43: 1-82.

Fang, H.H.P., Y.Y. Li and H.K. Chui, 1995. UASB treatment of wastewater with concentrated mixed VFA. J. Environ. Eng., 12: 153-160.

Gerritse, J. and J.C. Gottschalk, 1992. Mineralization of the herbicide 2,3,6-trichlorobenzoic acid by a co-culture of anaerobic and aerobic bacteria. FEMS Microbiol. Ecol., 101: 89-98.

Gonzalez, G., P.N.L. Lens, A.V. Aelst, A.H. Van, A.I. Versprille and G. Lettinga, 2001. Cluster structure of anaerobic aggregates of an expanded granular sludge bed reactor. Applied Environ. Microbiol., 67: 3683-3692.

Hulshoff Pol, L.W., 1989. The Phenomenon of granulation of anaerobic sludge. Ph.D Thesis, Wageningen Agriculture University, The Netherlands.

Lettinga, G. and H. Pol, 1991. UASB process design for various types of wastewaters. Water Sci. Technol., 24: 87-107.

Ligero, P. and M. Soto, 2002. Sludge granulation during anaerobic treatment of pre-hydrolysed domestic wastewater. Water SA., 28: 307-311.

Malina, J.F. and F.G. Pohland, 1992. Design of Anaerobic Processes for the Treatment of Industrial and Municipal Wastes. Water Quality Management Library, Vol. 7, Technomic Publishing Co., Lancaster, PA.

Metcalf and Eddy Inc., 2003. Wastewater Engineering, Treatment and Reuse. 4th Edn., McGraw Hill, New York, America.

Punal, A., P. Melloni, E. Roca, A. Rozzi and J.M. Lema, 2001. Automatic start-up of UASB reactors. J. Environ. Eng., 127: 397-402.

Sayed, S., L. van Campen and G. Lettinga, 1987. Anaerobic treatment of slaughterhouse waste using a granular sludge UASB reactor. Biol. Wastes, 21: 11-28.

Torkian, A., M. Amin, R.K. Kermanshahi, R. Iranpour, 2003. Pre and post-granulation performance of UASB system treating high-strength industrial effluent. Proc. WEF-Tech, Los Angeles, Ca., USA.

Van Haandle, A.C. and G. Lettinga, 1994. Anaerobic Sewage Treatment-A Practical Guide for Regions with a Hot Climate. J. Wiley and Sons.

Yang, G. and G.K. Anderson, 1993. Effects of wastewater composition on stability of UASB. J. Environ. Eng., 119: 958-977.